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ISOTHERMAL TECHNOLOGY HOMOGENEITY SCANNER MEASUREMENT FOR RECOVERY 10024

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Isothermal Technology Homogeneity Scanner

Measurement for Recovery 10024

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ABSTRACT

Thermocouple inhomogeneity is a significant source of uncertainty in thermocouple measurements. By measuring the inhomogeneity, the uncertainty component can be accurately calculated. In this investigation, Isothermal Technology's (Isotech) Model 881 Homogeneity Scanner, which operates at around 100 °C was compared with the NPL's homogeneity scanner, which operates at between about 600 °C and 900 °C. The temperature profile for each scanner was characterised, and the homogeneity signature of a used Type B and a used Pt-Pd thermocouple were measured with the two devices and compared with respect to the position dependence of the signal. The temperature dependence of the homogeneity signature of the same two thermocouples was assessed with the NPL scanner to provide guidance on the extrapolation of the Isotech scanner measurements to higher temperatures, and to confirm findings reported in the literature. It is found that, within the constraints of this type of measurement, the Model 881 scanner is consistent with the NPL scanner.

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CONTENTS

1 INTRODUCTION

Thermoelectric inhomogeneity is a feature that arises in thermocouples when any part of the length is exposed to a temperature that causes a change in the microstructure, such as high temperature or contamination. Inhomogeneity in the part of the thermocouple exposed to a temperature gradient will cause a deviation in emf from that of the ‘as-new’ purely homogeneous thermocouple, which leads to a measurement error and a larger measurement uncertainty. By having an apparatus with two distinct zones at different but constant temperatures, with a sharp and well-defined temperature gradient in-between them, the homogeneity of a thermocouple can be assessed [1] [2].

In this report, Isothermal Technology’s (Isotech) Model 881 Homogeneity Scanner is compared with NPL’s homogeneity scanner. Whilst they operate at different temperatures (100 °C for the former and between 600 °C and 900 °C for the latter), previous studies [3] suggest that the shape of the inhomogeneity signature of a thermocouple should be the same at different temperatures, provided the thermocouple is not subject to further degradation between the two measurements.

2 SCANNER APPARATUS

2.1 NPL HOMOGENEITY SCANNER

The experimental set up used was based on the design of the Measurement Standards Laboratory of New Zealand and is similar to that used in previous homogeneity scanning experiments at NPL [1]. It consisted of a Carbolite CTF 12/100 single zone furnace with a Eurotherm 808 Controller containing a 1 m long sodium heat pipe, and a quartz tube spanning the length of the furnace. The scanner can operate with the heatpipe between 600 °C to 900 °C, where the thermocouples are inserted in air.

In order to provide a lower temperature zone at a stable temperature and a sharp temperature gradient, a housing is situated at the entrance of the furnace. The entrance apparatus, labelled “cold zone” in Figure 1, is made of thick silicon discs layered with platinum foil, all contained inside a ceramic casing, which contains a water-cooled jacket. This is connected to a Grant T100-R1 temperature-controlled water bath with a Grant TC120 digital thermostat set to 10 °C.

Motion control for the scanner is provided by a Parker HD085 linear actuator and Micromech Ltd controller. LabVIEW software developed previously [1] was used for automation, data logging, and communication with the digital voltmeter (DVM).

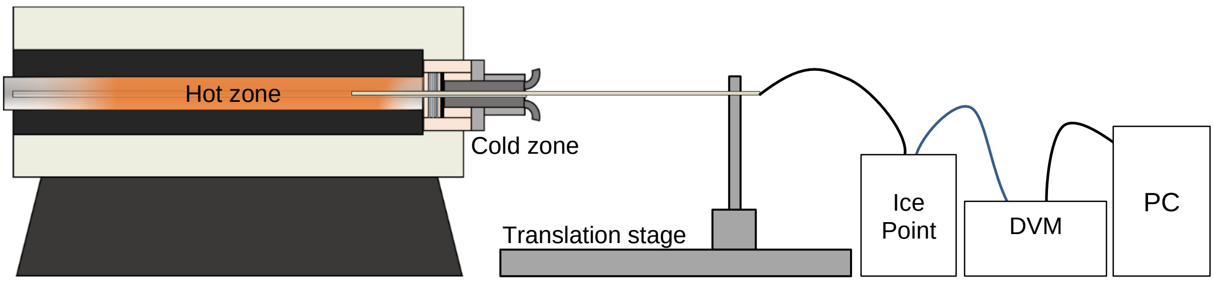

Figure 1 NPL’s homogeneity scanner and peripheral equipment.

2.2 MODEL 881 HOMOGENEITY SCANNER

The experimental set up used is similar to the NPL scanner, in that it has a hot zone and a cold zone. The Model 881 consists of a 1 m long steam heat pipe, where the thermocouples are directly exposed to steam, and a 70 mm long acetone heat pipe at the entrance, which is kept at 20 °C. These heat pipes are separated by a septum that provides the short temperature gradient. The scanner operates at 100 °C.

Motion control for the scanner is provided by a worm driven linear actuator. Another version of the LabVIEW software developed previously [1] was used for automation, data logging, and communication with the DVM.

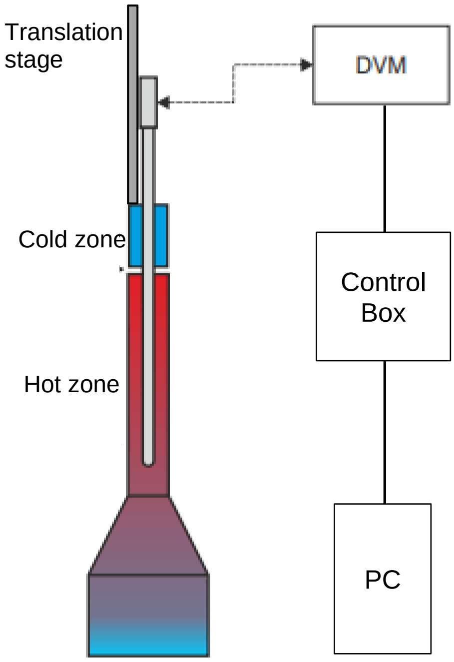

Figure 2 Isotech Homogeneity Scanner and peripheral equipment.

2.3 MEASUREMENT EQUIPMENT

For both scanners, a Keithley 2182A nano-voltmeter was used to log the thermocouple measurements. For the NPL scanner, a separate Fluke Calibration 9101 Zero-point Dry-Well was used for the thermocouple cold junction, and for the Model 881, internal cold junction compensation was used. Data collection occurred as the thermocouple was being inserted into the furnace.

3 SCANNER PROFILING

3.1 SET UP

To check that the hot zones of each scanner were uniform, the temperature profile of the scanners were characterised. This was performed at 100 °C for the Model 881, and at the minimum operating temperature for the NPL scanner, 600 °C. The profiles were measured with a standard Pt-Pd thermocouple, in order to check that the uniform temperature parts within the heat pipes were isothermal, and to provide information on the critical temperature gradient region.

3.2 PROFILES

The profiles of the temperature gradients of the Model 881 and the NPL scanner can be seen in Figures 3 and 4 respectively. The point corresponding to 0 cm insertion on the Model 881 is where the thermocouple is fully inserted into the acetone heat pipe. This point on the NPL scanner corresponds to the point where the thermocouple is fully inserted into the cold zone, which is 110 mm into the apparatus.

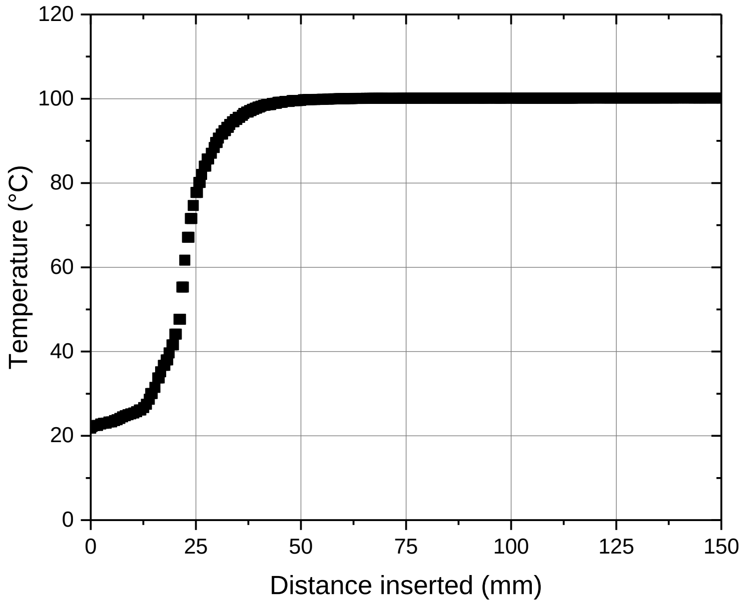

Figure 3 Graph showing the temperature gradient of the Model 881 between 0 mm insertion to 150 mm insertion. Note that the actual gradient is between 0 mm and 50 mm.

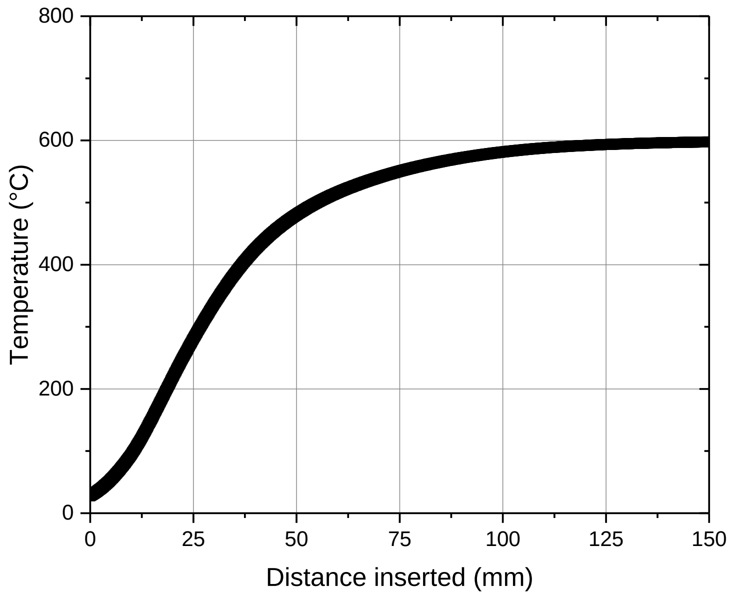

Figure 4 Graph showing the temperature gradient of the NPL scanner between 0 mm insertion to 150 mm insertion.

The profiles of the two scanners are as expected, in that they both show an increase of temperature from ambient temperature to the heat pipe temperature. Whilst the gradient in the Model 881 is not as smooth, it is much shorter, amounting to 50 mm compared to the 150 mm seen in the NPL scanner. This improved length is probably due to the much smaller difference in temperature across the gradient, and the septum piece in the Model 881 that separates the hot and cold zones from each other.

4 THERMOCOUPLE HOMOGENEITY SCANS

4.1 COMPARING DEVICES

The homogeneity signature of two thermocouples was measured at 100 °C with the Model 881, and at 600 °C with the NPL scanner. Each of the two thermocouples was scanned three times in each scanner. The thermocouples selected to be scanned were a Pt/Pd and a Type B, both having been previously exposed to high temperatures for over 1000 hours.

The emf was measured continuously whilst the thermocouple was inserted into the scanner, and *dE* was calculated using the formula $dE = E_{measured} - E_{ref}$, where $E_{measured}$ is the measured emf at that point in the furnace, and E_{ref} is the reference emf at the nominal measured hot zone temperature, which here is measured at 300 mm insertion into the hot zone in both scanners.

The reason that *dE* was chosen over the fractional change in the Seebeck coefficient *dS/S* is due to the unique nature of type B thermocouples, where the Type B Seebeck coefficient rises steadily with temperature instead of remaining relatively constant. The emf difference *dE* was considered to give a more direct visualisation.

Each scan took 10 minutes in the Model 881 and 30 minutes in the NPL scanner.

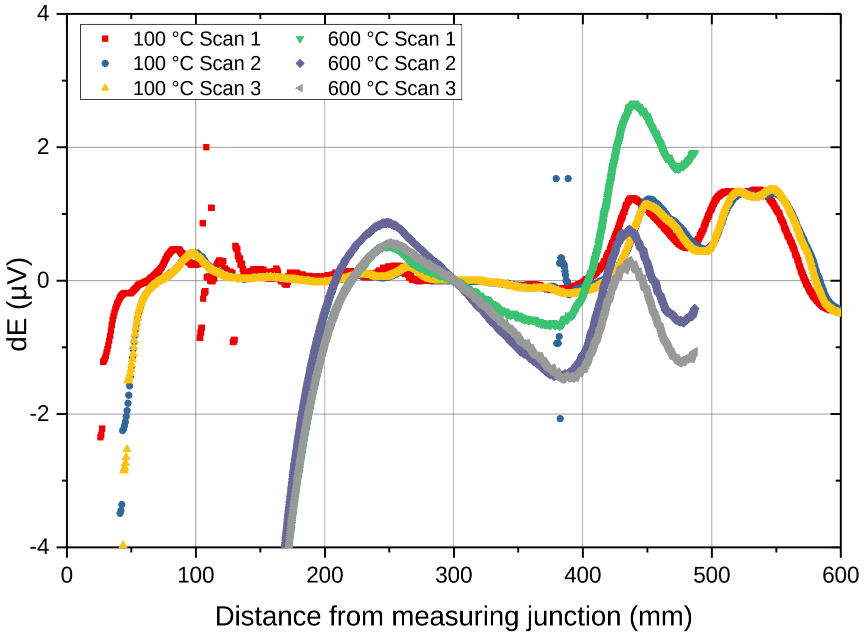

Figure 5 A graph of the homogeneity scans of the Type B thermocouple, where the x axis is the distance of the thermocouple tip from the sharp temperature gradient. The 100 °C scans were performed in the Model 881 and the 600 °C scans in the NPL scanner. The spikes seen at 100 mm and 400 mm for the scans at 100 °C are due to noise created by the thermocouple extension wires moving during the scan.

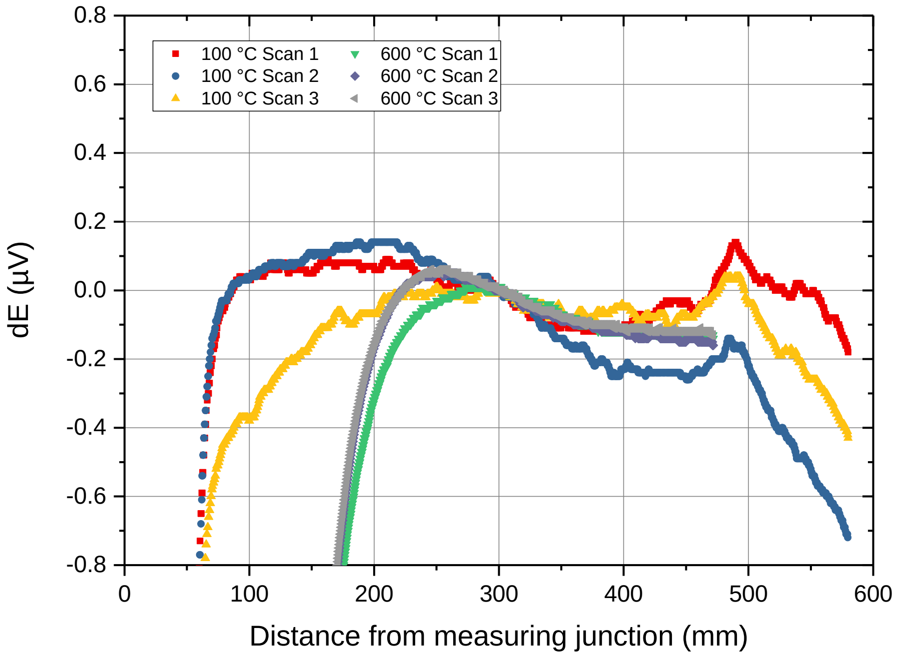

Figure 6 A graph of the homogeneity scans of the Pt-Pd thermocouple, where the x axis is the distance of the thermocouple tip from the sharp temperature gradient. The 100 °C scans were performed in the Model 881 and the 600 °C scans in the NPL scanner.

For the Pt/Pd scans, those performed at 600 °C have been scaled by a factor $E_{ref}(T_{100})/E_{ref}(T_{600})$ for convenience, so that they can be directly compared. This same scaling was not applied to the Type B results, as this same scaling factor has not been proven for Type B thermocouples below 600 °C [4], and it was found to be inappropriate here.

It can be seen from both Figures 5 and 6 that whilst the temperature and temperature gradient is different for each scanner, the thermocouple's underlying inhomogeneity signature has a similar shape in both. This applies to both the Pt/Pd and the Type B thermocouple. This is demonstrated best in Figure 5 by the common peak at approximately 440 mm, but the peak at 250 mm was less obvious in the scans at 100 °C. Similarities can be seen in Figure 6 between the scans made at different temperatures from the peak at around 220 mm, and the relatively smooth section between 250 mm and 450 mm.

The differences seen in the homogeneity signatures between 250 mm and 380 mm in Fig 5 may be due to in-situ oxidation effects caused by the scans carried out at 600 °C.

Another aspect that is clear from Figures 5 and 6 is the shorter temperature gradient provided by the Model 881 scanner, which is short enough that the thermocouple is at the nominal heat pipe temperature when inserted by 100 mm, and sometimes only by 50 mm. A thermocouple in the NPL scanner on the other hand will not reach the nominal heat pipe temperature until it's inserted approximately 200 mm into the heat pipe.

Another difference between the two scanners is that due to the NPL scanner cold zone being longer, only 490 mm of the thermocouples was able to be scanned, compared to 600 mm in the Model 881.

4.2 COMPARING TEMPERATURES

The temperature dependence of the homogeneity signature of the Type B thermocouple was assessed with the NPL scanner, to provide guidance on the extrapolation of the Model 881 measurements to higher temperatures, and to confirm findings reported in the literature. It has been shown previously that the deviations in emfs caused by homogeneities in thermocouples scale approximately linearly with the ratio of the emfs at the two temperatures. This scalability allows uncertainties assessed at one temperature, to be extrapolated to other temperatures [5].

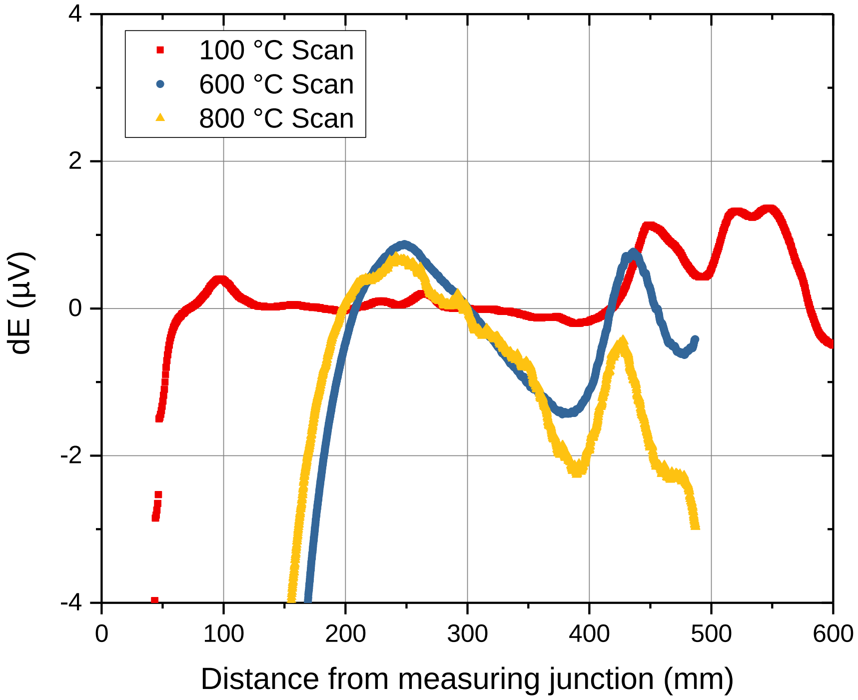

Figure 7 A graph of the homogeneity scans of the Type B thermocouple at 100 °C in the Model 881, and at 600 °C and 800 °C in the NPL homogeneity scanner.

It can be seen from Figure 7 that, unsurprisingly, increasing the temperature increases the magnitude of the variation in emf due to inhomogeneity, and also that the changes seen at 100 °C can be used to infer similar changes at 600 °C and 800 °C. A good example of this is the peak and trough seen at between 400 and 450 mm at all three different temperatures. The apparent shift in the peak position depending on temperature is thought to be due to the changing temperature gradient in the NPL scanner as the temperature changes.

What is also apparent is that features of the homogeneity pattern that are not present at lower temperatures are visible at higher temperatures, namely the steady decrease between 250 mm and 400 mm, which is just visible at 100 °C but not significant. Studies have shown that minimum temperature for the thermoelectric scan of a type B thermocouple was found to be 600 °C using a sodium-heat pipe furnace [4], so this behaviour was for the Type B thermocouples. It is promising that some features were still detectable at 100 °C, but it is evident from Figure 7 that scaling from 100 °C to higher temperature for Type B thermocouples would present some problems.

5 CONCLUSIONS

To summarise, the Model 881 scanner is reasonably consistent with the NPL scanner. Some variability is to be expected on account of the very different temperatures and temperature profiles, but it is clearly effective at detecting inhomogeneities in both Pt-Rh and Pt-Pd based thermocouples. Its very short temperature gradient and small cold zone mean it can scan a longer length of thermocouple than the NPL scanner, with considerably higher spatial resolution. It is expected that for Type R and S thermocouples, these inhomogeneities can be scaled using established methods to calculate the uncertainty at higher temperatures.

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